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RESEARCH DEPARTMENT

The performance of two 10 : 1 zoom lenses for the image orthicon format: the Angenieux 10 x 35E3 and 10 x 35E5

TECHNOLOGICAL REPORT No. PH-10

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THE BRITISH BROADCASTING CORPORATION
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SUMMARY

The performance of the lens type 10 × 35E3 (No. 1156743) is described in detail in respect of modulation transfer function at short and infinite conjugates, vignetting, veiling glare, transmission and geometrical distortion.

The performance of the lens type 10 × 35E5 (No. 1165221) is described only in sufficient detail to demonstrate that an improvement in geometry has not been obtained by an impairment in performance in other respects.

A figure of merit describing the image quality is derived for each tested focal length.

1. INTRODUCTION

The two lenses types 10 × 35E3 and 10 × 35E5 are developments of a previously-described zoom lens, the improved type 10 × 35B[1], which was marketed as the type 10 × 35E1. This lens will henceforth be referred to as the type 10 × 35B(E1).

Brief specifications type 10 × 35B(E1) lens, and of the two zoom lenses derived from it, are given below:

	10 × 35E3	10 × 35B(E1) and 10 × 35E5
Focal length range	35 to 350 mm	35 to 350 mm
Maximum aperture	f/3·8	f/3·8
Image format	24·4 × 32·5 mm	24·4 × 32·5 mm
Near object distance	400 mm	960 mm

The small minimum object distance of the type 10 × 35E3 lens entailed the introduction of an enlarged front element, with a corresponding increase in weight.

The lens type 10 × 35E5 has the same general specification as that of the type 10 × 35B(E1) lens, the major difference being improved geometry (i.e. lack of distortion) over the focal length range. Reference to the 10 × 35B(E1) test report shows that the geometrical distortion is equal in magnitude but opposite in sign at the extremities of the focal length range, the changeover in the type of distortion occurring at about 60 mm focal length. It was suggested that a more acceptable subjective result would be obtained by redesigning the lens to give smaller distortions at the longer focal lengths, the distortion possibly increasing at the shortest focal lengths. This would be expected to result in a smaller distortion over the major portion of the focal length range. In actual fact, the increase in distortion at the shortest focal length has been avoided and the 10 × 35E5 has no greater distortion at a focal length of 35 mm than the 10 × 35E3 lens. Operational experience with this lens type has confirmed an improved subjective impression of picture geometry.

Measurements of modulation transfer function (m.t.f.) were carried out to check that the redesign resulting in a reduction of geometrical distortion had not simultaneously produced an impairment of the image sharpness. It was considered that the m.t.f. would be the most sensitive parameter of the lens to check that there was no impairment in overall performance.

2. MEASUREMENTS

2.1. Modulation Transfer Function

2.1.1. Lens Type 10 × 35E3

Measurements of m.t.f. were made at seven focal length settings for both the maximum aperture of f/3·8 and one stop down at f/5·6, the test object being located at infinity. The lens was adjusted by the normal method of successive approximation to the zoom focus condition; the focus was however further adjusted at each tested focal length to give the maximum 9 c/mm* modulation on axis, no account being taken of any zoom tracking error.

The results with the test object at infinity are shown in Figs. 1 to 7 for operation at f/3·8, and in Figs. 8 to 14 for operation one stop down at f/5·6.

The m.t.f. was also determined with the test object located 400 mm from the front of the lens. The curves are shown in Figs. 15 to 21. The dimensions of the test bench cross slide precluded measurements near the periphery of the image at the very widest angle settings of the zoom range (i.e. shortest focal length).

The m.t.f. curves are typical of the Angenieux "family" of 10 : 1 zoom lenses. For the focal length range of 35 to 150 mm the performance is good irrespective of object distance. From 150 to 350 there is some impairment and this becomes more marked at the shortest object distance.

2.1.2. Lens Type 10 × 35E5

The m.t.f. was measured at four focal lengths only, namely 35, 60, 150 and 350 mm, the test object being effectively located at infinity and the lens aperture set to the maximum of f/3·8. The m.t.f. curves are shown in Figs. 22 to 25. Comparison with the corresponding curves of the lens type 10 × 35E3, i.e. Figs. 1, 3, 5 and 7 show a considerable similarity when the tangential and sagittal plane results are averaged. The agreement in performance was considered sufficient to assume that the overall performance of the two lens types would be very similar.

For convenience of comparison, the variation over the focal length range of the modulation transfer factor at 8·9 c/mm is plotted for the various test conditions in Figs. 26 to 29. Comparison of Figs. 26 and 27 shows the improvement in performance resulting from stopping down the 10 × 35E3 lens from f/3·8 to f/5·6; the improvement in m.t.f. over the zoom range varies between 5 and 15%. Fig. 28 shows the deterioration in performance at the long focal length end of the zoom range, when the lens is operated with the test object located at the near working distance of 400 mm*. Fig. 29 compares the m.t.f. at 8·9 c/mm for the two lens types 10 × 35E3 and 10 × 35E5, the similarity in performance is marked.

2.2. Vignetting

The vignetting characteristics of the lens type 10 × 35E3 at full aperture are shown in Fig. 30. The vignetting characteristics are typical of the Angenieux range of 10 : 1 zoom lenses; a sharp cut-off in image illumination for short focal lengths changing to a continuous fall in image illumination over the image field for the longest focal lengths.

2.3. Transmission and Maximum Veiling Glare Index

2.3.1. Transmission

The transmission of the two lens types is given in the table below and is about 2% lower than that stated by the manufacturer[2].

Lens Type	Illumination Type			
	Tungsten	Red	Green	Blue
10 × 35E3	67·9	67·9	69·3	53·6
10 × 35E5	67·0	70·0	70·0	56·0

2.3.2. Maximum Veiling Glare Index

The variation of the veiling glare index over the focal length range of the two lens types at full aperture is shown in Fig. 31. The form of the curves is typical, the index decreasing with increasing focal length setting. The index of the type 10 × 35E5 lens is of particular interest, this lens having the lowest veiling glare index of any Angenieux zoom lens yet measured. Discussions with the manufacturer have revealed that this is the result of a redesign.

2.4. Geometrical Distortion

Measurements were made only on the type 10 × 35E3 lens. Fig. 32 shows the geometrical distortion of the lens at 35 mm and 60 mm focal length for both short and long conjugates. The curves are presented in accordance with the BBC specification for zoom lenses, TV/139[3]. The measurements were undertaken primarily to check agreement between the manufacturer's figures and

* A spatial frequency of 8·9 c/mm corresponds with the image orthicon format scanned by the British 625-line standard, to a frequency of 5·5 MHz.

* Note that the lens is performing at rather unusual conjugates when the test object is 400 mm distant and the focal length is 350 mm.

those of the BBC. Excellent agreement is in fact obtained when the different methods of presentation are taken into account. The manufacturer's data[2] for the type 10 × 35E5 is shown in Fig. 33.

The focal lengths chosen in Figs. 32 and 33 show the maximum geometrical distortion, i.e. maximum "barrel" distortion at the shortest focal length and maximum "pin cushion" distortion at focal lengths of 60 and 100 mm for the types 10 × 35E3 and 10 × 35E5 respectively.

3. PUPIL LOCATION

The location of the exit pupil is of interest if the lens is to be used with a colour camera. It is determined by the fixed rear element group of the lens; in the case of the 10 × 35E3 lens the exit pupil is 860 mm to the rear of the lens, for the 10 × 35E5 lens the exit pupil is some 4 metres to the rear.

The position of the entrance pupil is important with regard to the perspective of the image. The entrance pupil varies in position with changes in both focal length and focus setting as shown below:

object distance	distance of entrance pupil inside lens from front element, for focal length of			
	35 mm		350 mm	
	10×35E3	10×35E5	10×35E3	10×35E5
400 mm	120 mm		700 mm	
960 mm		90 mm		380 mm
infinity	90 mm	70 mm	50 mm	30 mm

4. IMAGE MAGNIFICATION

The magnification of a simple lens is given by $M = f/(x - f)$ where M = magnification, f = focal length and x = object distance measured to the front node of the lens. This relationship also holds for any compound (thick) lens system including a zoom lens, but its application is difficult in the case of a zoom lens for two reasons:

(i) the front node of the zoom lens varies with both focus and zoom settings, is not generally known and is not easily determined, (ii) the focal length for any focus setting other than infinity is not the value stated on the lens. Hence it is more helpful to evaluate the lens from a knowledge of the way in which it works. A simple model[4] of the Angenieux zoom lens can be constructed from the following three groups of optical elements:-

(1) A fixed rear-element group, including the iris, which determines the image format, rear-working distance and position of the exit pupil.

(2) A variable magnification group. Movement of members of this group of elements varies the magnification between two invariant object and image planes, and thus causes a variation in focal length.

(3) A variable position front focusing group; for varying object distances, movement of this group is arranged to give a constant image plane which serves as the invariant object plane described in (2).

Because the front focusing group is arranged to give a fixed image plane, the two other groups have for a given focal length, fixed image and object planes. The change in magnification with object distance is related only to the power of the front focusing group, and not to the particular focal length at which the lens is being used. The absolute magnification of the complete lens is related to both the power of the front focusing group and to the position of the variable power group. On the basis of this simple model, the following formula has been derived:-

$$M = f_0(x - f_1)$$

where f_0 = equivalent focal length of zoom lens

f_1 = equivalent focal length of front group of elements

In the present case $f_1 = -204$ mm

In the table below, image magnifications for different object distances produced by simple lenses of 35 and 350 mm focal length, are compared with those of the 10 × 35E3 zoom lens at the same focal length settings.

Image Magnification

Object distance	35 mm focal length		350 mm focal length	
	simple lens	zoom lens	simple lens	zoom lens
10 metres	0·00351	0·00343	0·0363	0·0343
1 metre	0·0362	0·0291	0·538	0·291
400 mm	0·0959	0·0579	7·0	0·579

For object distances much greater than the focal length setting, the difference in magnification between a simple lens and a zoom lens is small. for object distances comparable to the focal length, the difference in image magnification is considerable and large errors will result if it is assumed that the magnification of a zoom lens is similar to that of a fixed focus lens of the same focal length.

Thus, for the particular zoom lens type 10 × 35E3 at 350 mm focal length and an object distance of 400 mm, the magnification is only one-twelfth that of a simple lens for similar working conditions. Thus a real object of 56 mm by 42 mm fills the field when the type 10 × 35E3 is used under these conditions.

5. SUBJECTIVE ASSESSMENT

The subjective assessment of the image sharpness at any position in the image field may be related to the modulation transfer function curve integrated up to the cut-off frequency[5]. An assessment of the image sharpness quality over the entire image field may be obtained by further integration, taking into account the variation in visual importance over the image field[6].

Fig. 34 shows the subjective assessment of image sharpness (expressed in limens)[5] of the 10 × 35E3 lens over the entire image field, for the three test conditions (namely f/3·8 and f/5·6 object at infinity, and f/3·8 with the object at 400 mm). Over the major part of the focal length range the impairment is near to or better than 1 limen. The impairment increases with increase of focal length, especially at the close working distance; however, the operational performance of the lens is more important at the short end of the focal length range.

Fig. 35 allows comparison at full aperture of the performance of the lenses types 10 × 35E3, 10 × 35E5 and 10 × 35B(E1). The 10 × 35E3 and 10 × 35E5 results are in very good agreement and are slightly superior in assessment of image sharpness to the 10 × 35B(E1) zoom lens.

6. CONCLUSIONS

The lenses types 10 × 35E3 and 10 × 35E5 at full aperture will give very good quality over the greater part of the zoom range. When stopped down, the performance improves to give excellent image quality over the entire zoom range. Operation of both lens types at their respective nearest working distances results in some impairment in image quality, this being more marked at the long focal length settings.

7. REFERENCES

1. Performance of 10 to 1 zoom lens for image orthicon format: (Type 10 × 35B No. 1095308). BBC Research Department Report No. T-144, Serial No. 1965/6.

2. Angenieux Technical Data Sheets 161-49, 480-14, 480-15, for the Angenieux 10 × 35E5 f/3·8 zoom lens.

3. BBC Specification No. TV/139 for zoom lenses.

4. An introduction to Angenieux 10: 1 zoom lenses, Data Sheet E.P.O. 25, Evershed Power-Optics Ltd.

5. SPROSON, W.N. 1958. The subjective sharpness of television pictures. *Electron. Radio Engr.*, 1958, **35**, 4, pp. 124 - 132.

6. SPROSON, W.N. 1957. New equipment and methods for the evaluation of the performance of lenses for television. *BBC Engng Monogr.*, 1957, No. 15.

Figures
1 — 35

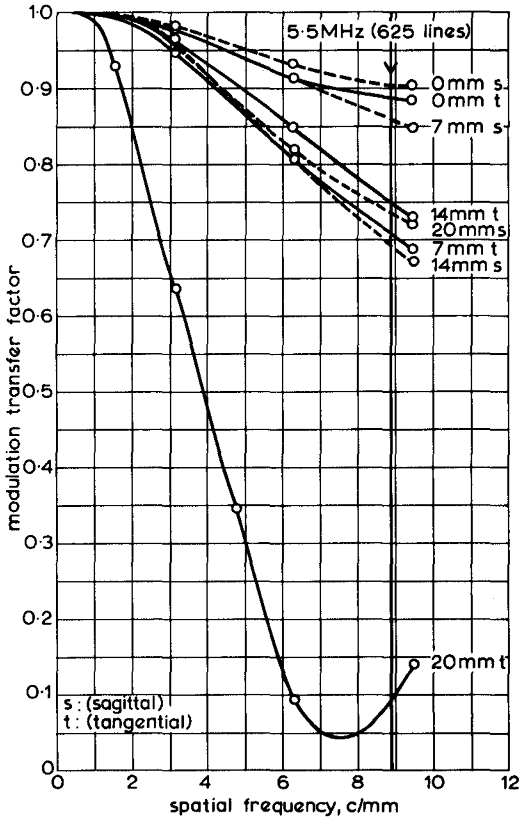

Fig. 1 - 35 mm focal length at f/3·8

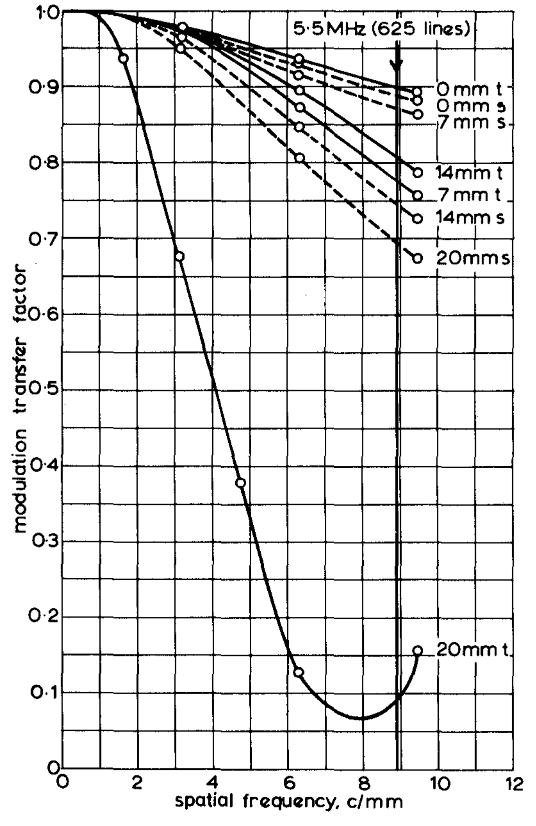

Fig. 2 - 45 mm focal length at f/3·8

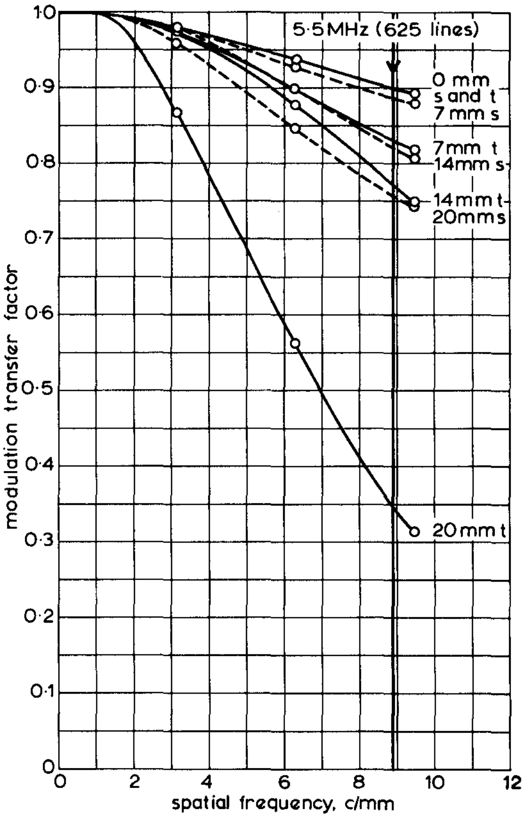

Fig. 3 - 60 mm focal length at f/3·8

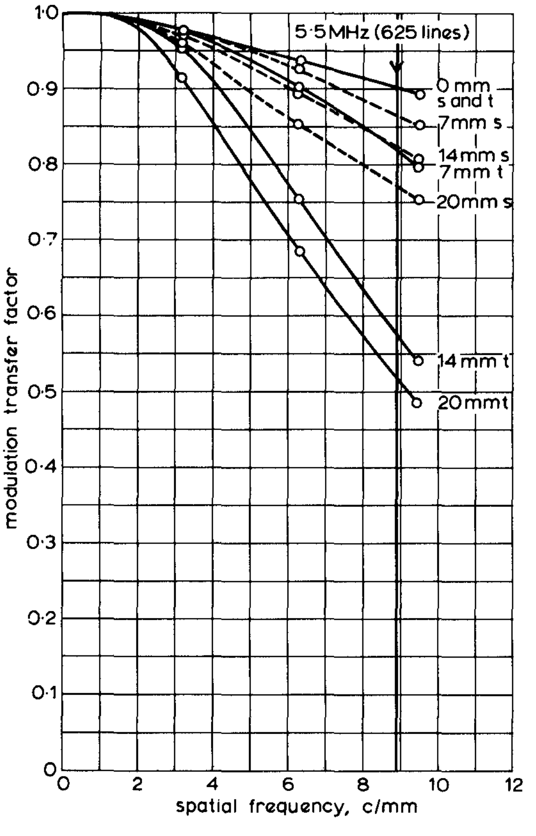

Fig. 4 - 100 mm focal length at f/3·8

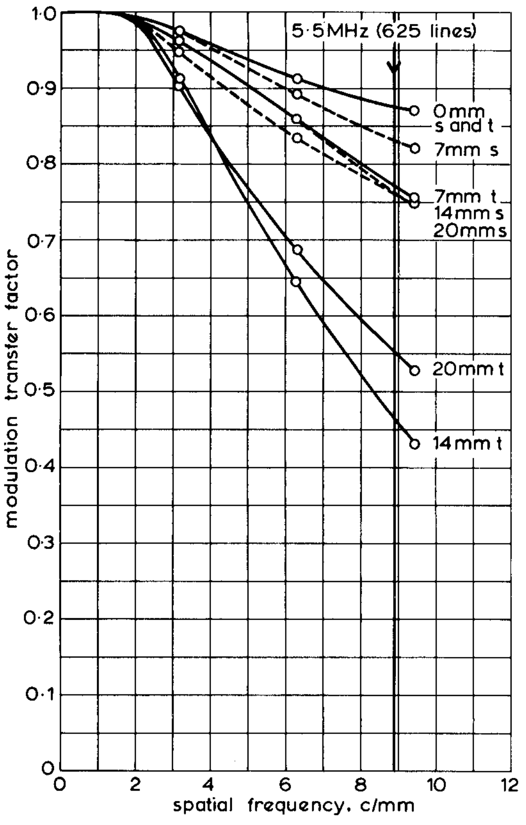

Fig. 5 - 150 mm focal length at f/3·8

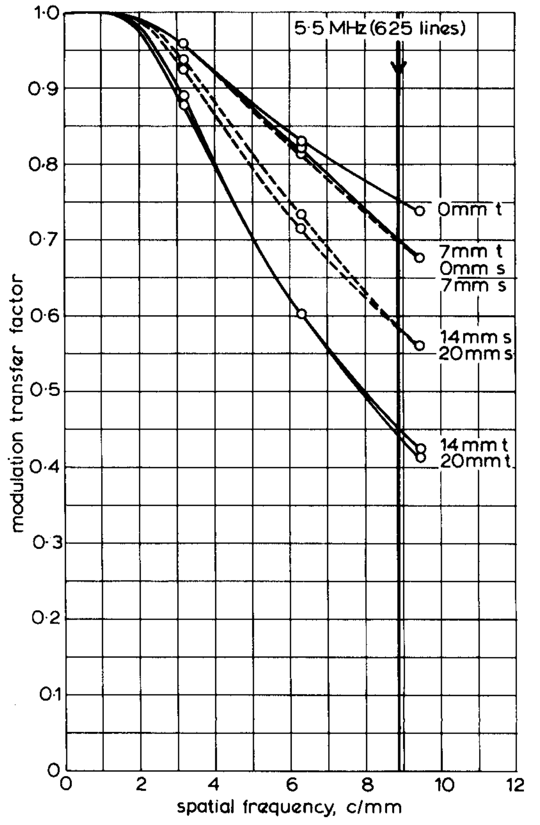

Fig. 6 - 260 mm focal length at f/3·8

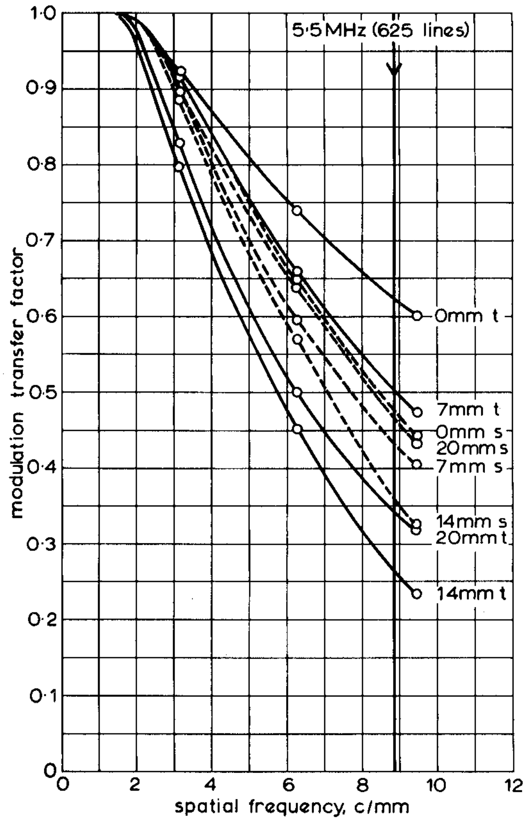

Fig. 7 - 350 mm focal length at f/3·8

Figs. 1 to 7 - Modulation transfer function 10 × 35E3 zoom lens at f/3·8. Test object at infinity, optimum axial 9 c/mm focus

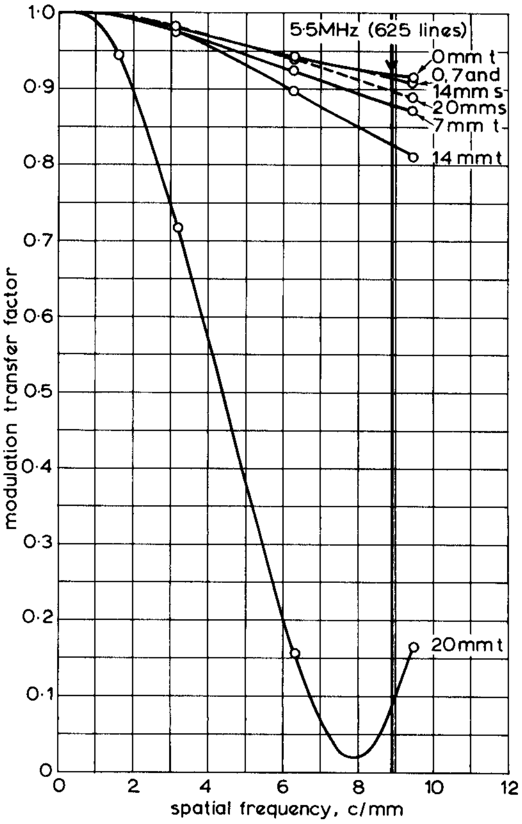

Fig. 8 - 35 mm focal length at f/5·6

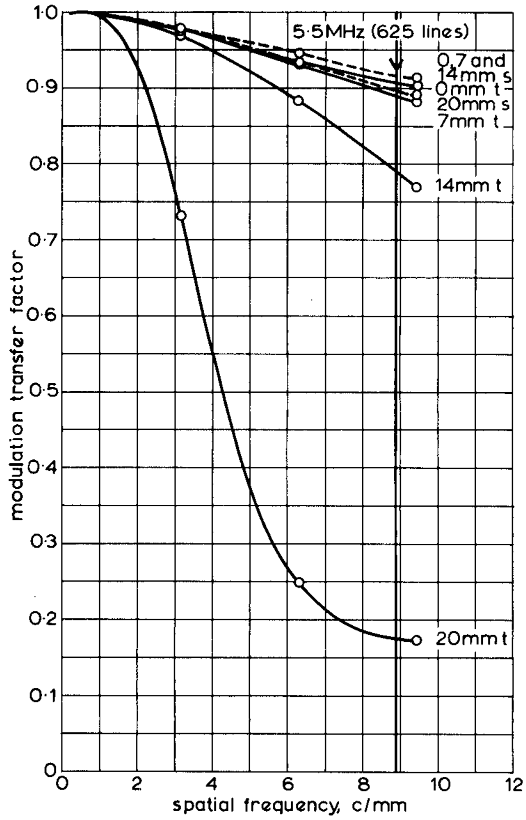

Fig. 9 - 45 mm focal length at f/5·6

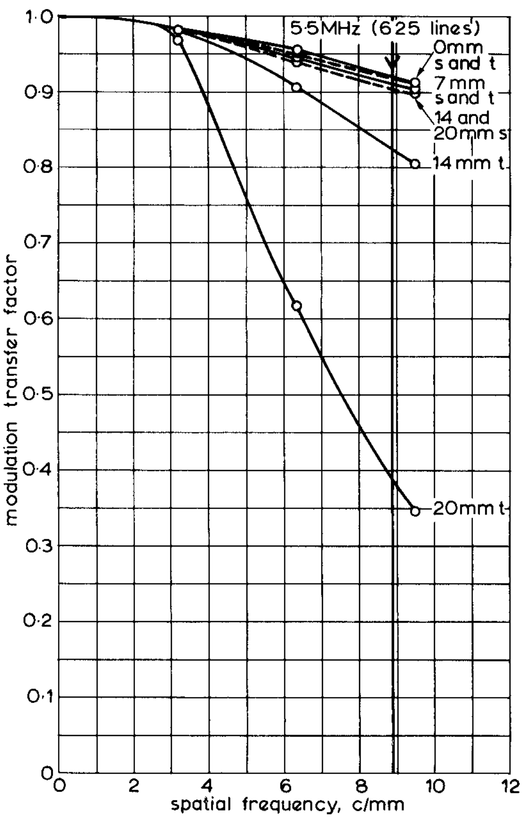

Fig. 10 - 60 mm focal length at f/5·6

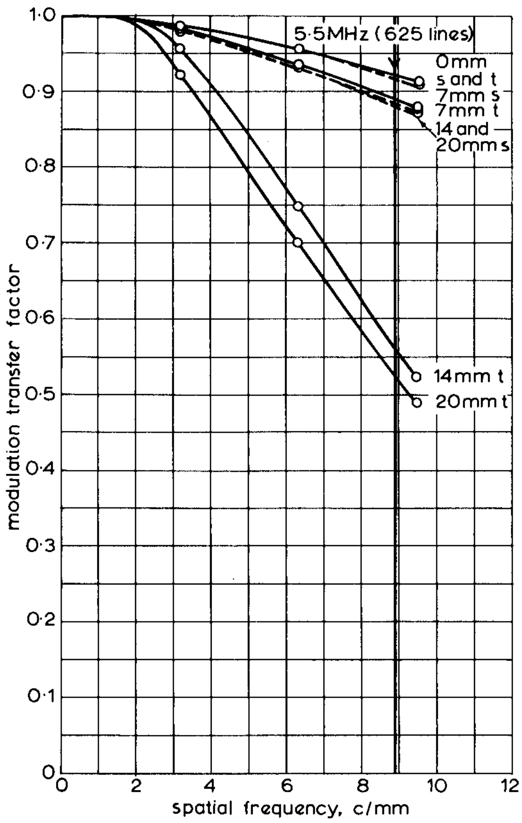

Fig. 11 - 100 mm focal length at f/5·6

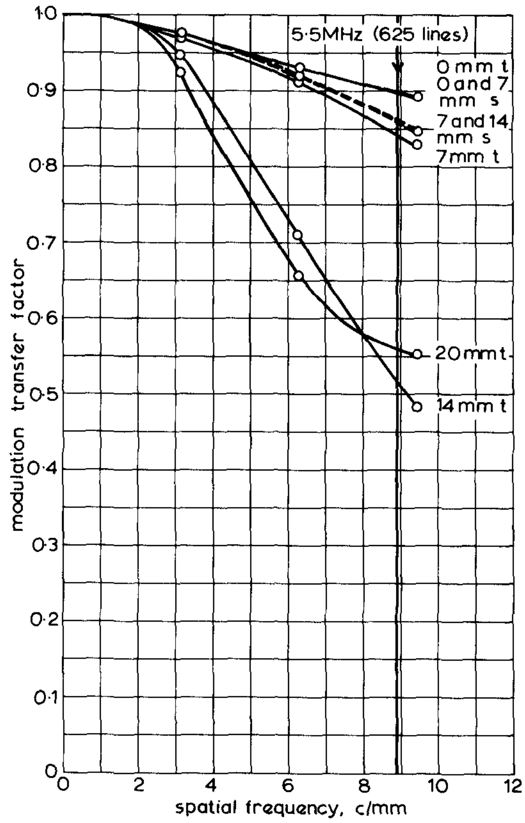

Fig. 12 - 150 mm focal length at f/5·6

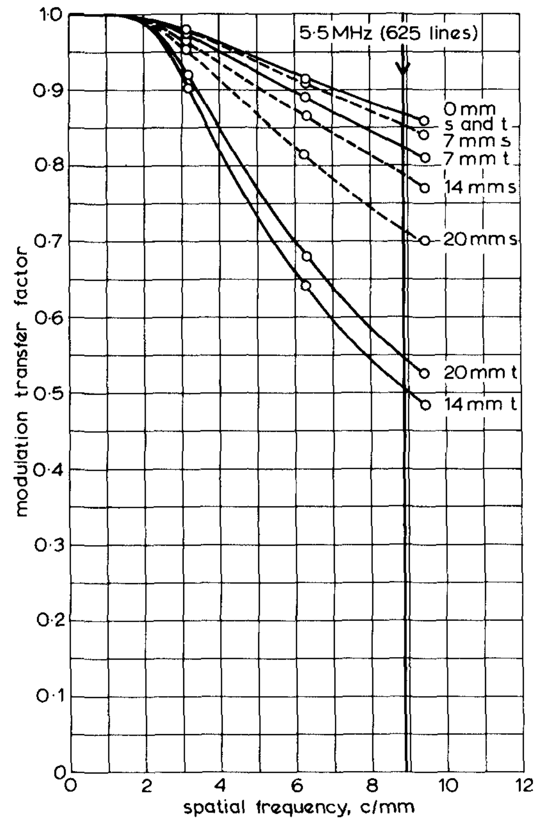

Fig. 13 - 260 mm focal length at f/5·6

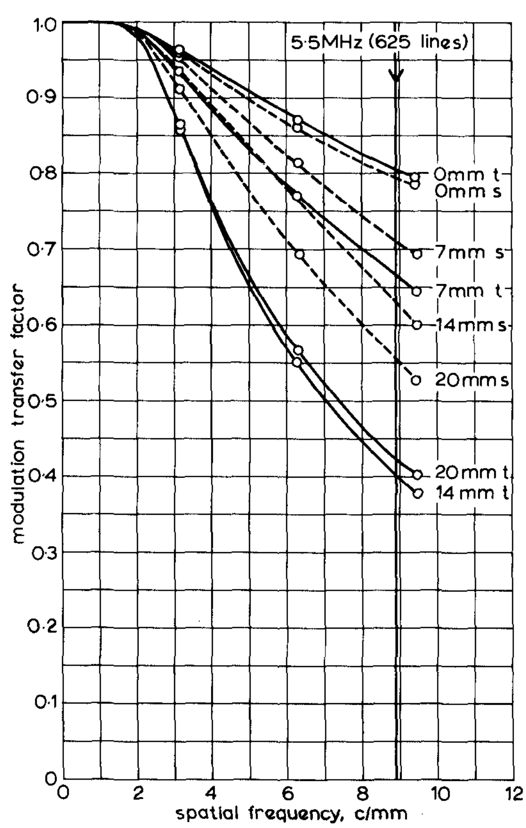

Fig. 14 - 350 mm focal length at f/5·6

Figs. 8 to 14 - Modulation transfer function 10 × 35E3 zoom lens at f/5·6. Test object at infinity, optimum axial 9 c/mm focus

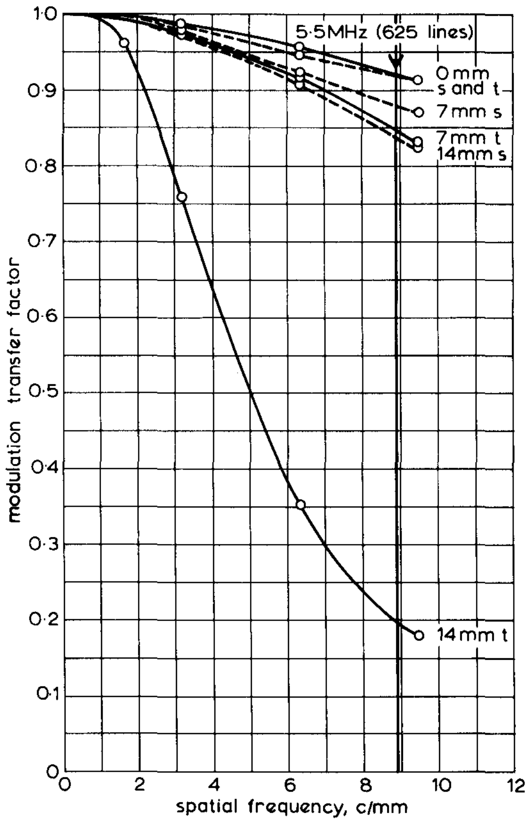

Fig. 15 - 35 mm focal length at f/3·8

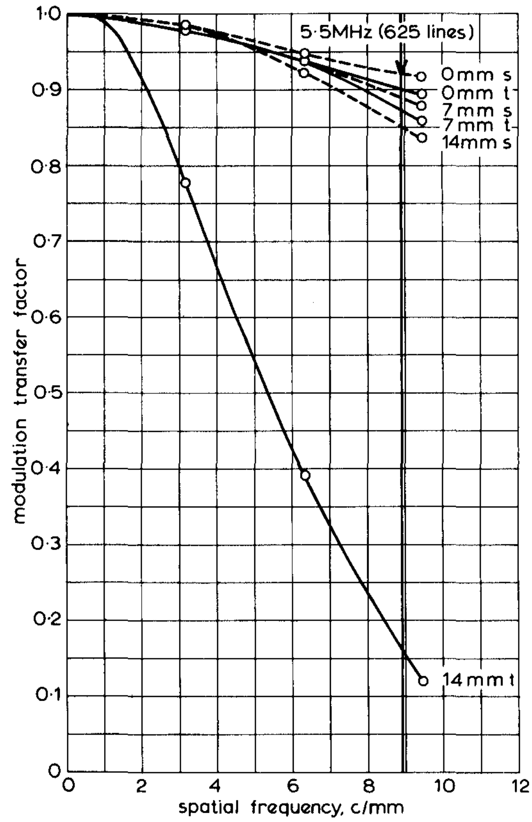

Fig. 16 - 45 mm focal length at f/3·8

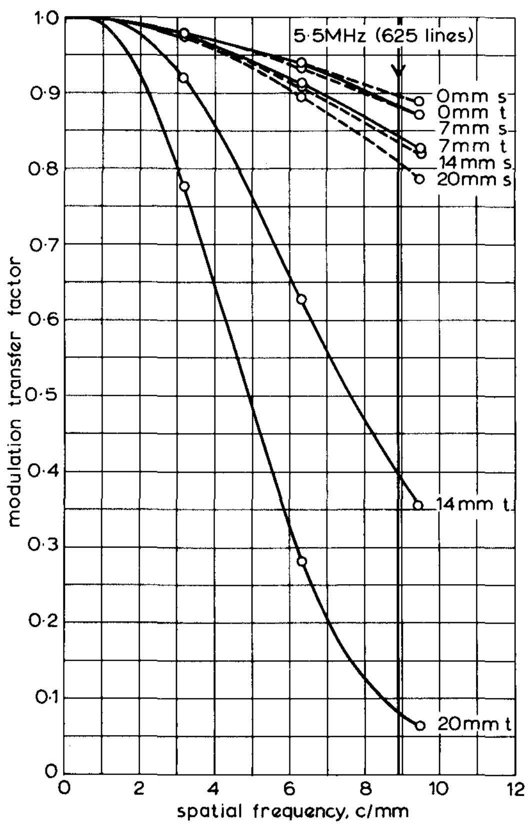

Fig. 17 - 60 mm focal length at f/3·8

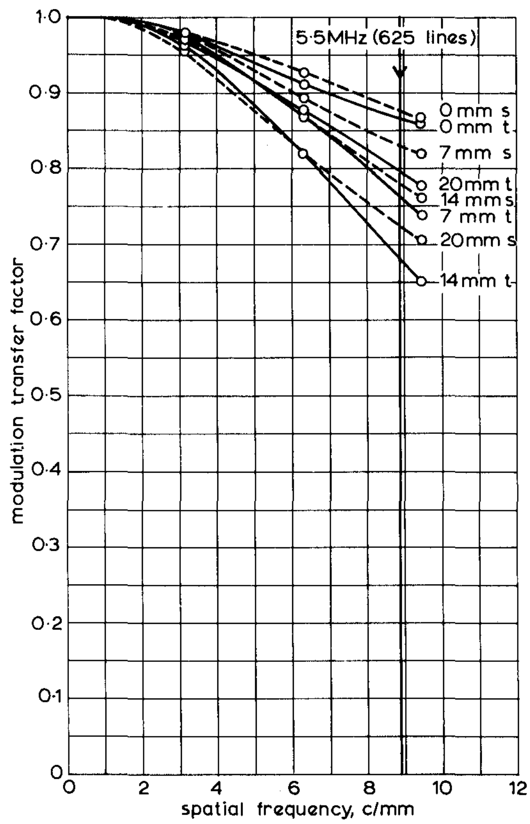

Fig. 18 - 100 mm focal length at f/3·8

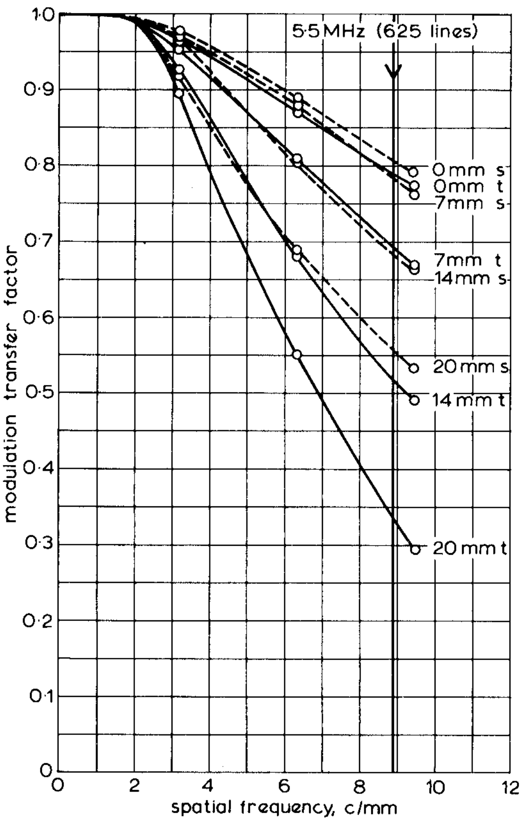

Fig. 19 - 150 mm focal length at f/3·8

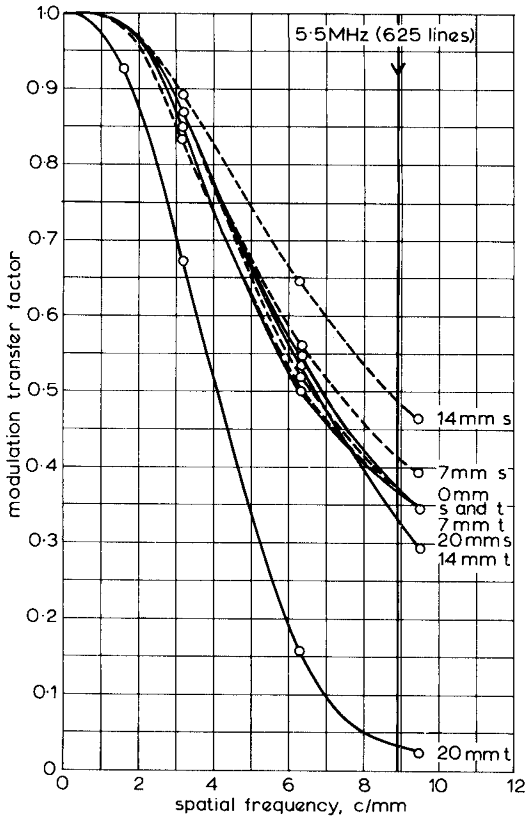

Fig. 20 - 260 mm focal length at f/3·8

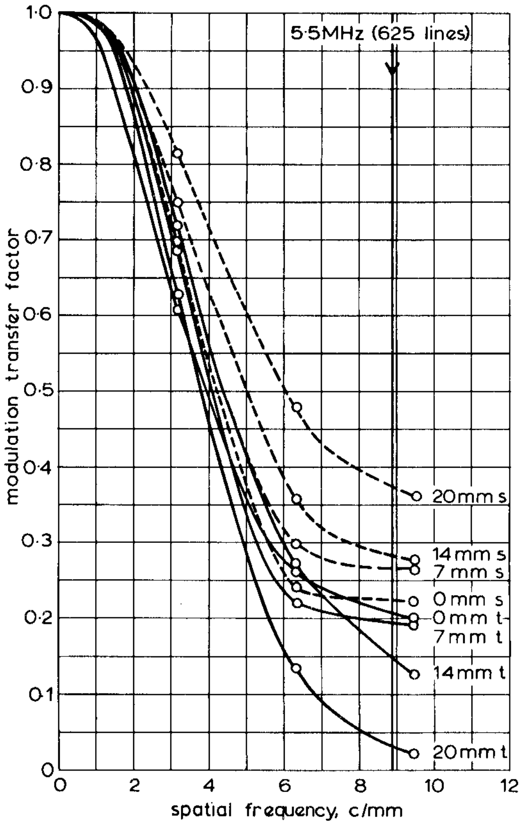

Fig. 21 - 350 mm focal length at f/3·8

Figs. 15 to 21 - Modulation transfer function 10 × 35E3 zoom lens at f/3·8. Test object at 400 mm, optimum axial 9 c/mm focus

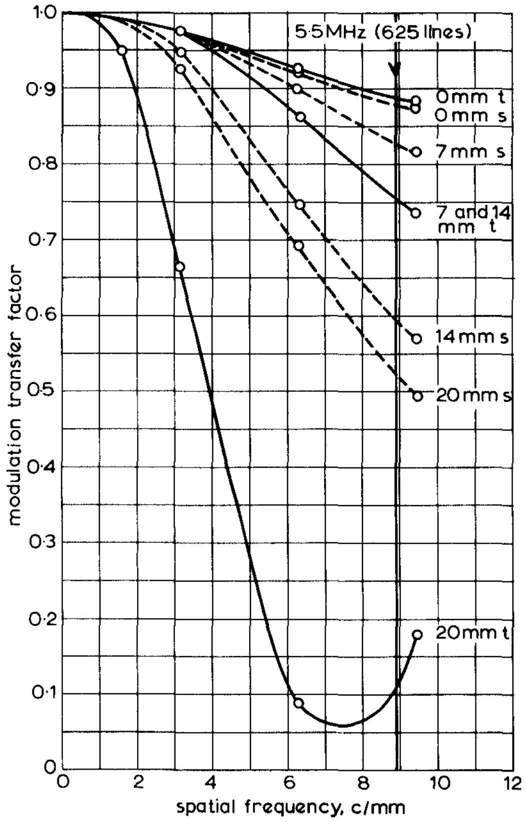

Fig. 22 - Modulation transfer function 10 × 35E5 zoom lens. 35 mm focal length at f/3·8, test object at infinity, optimum axial 9 c/mm focus

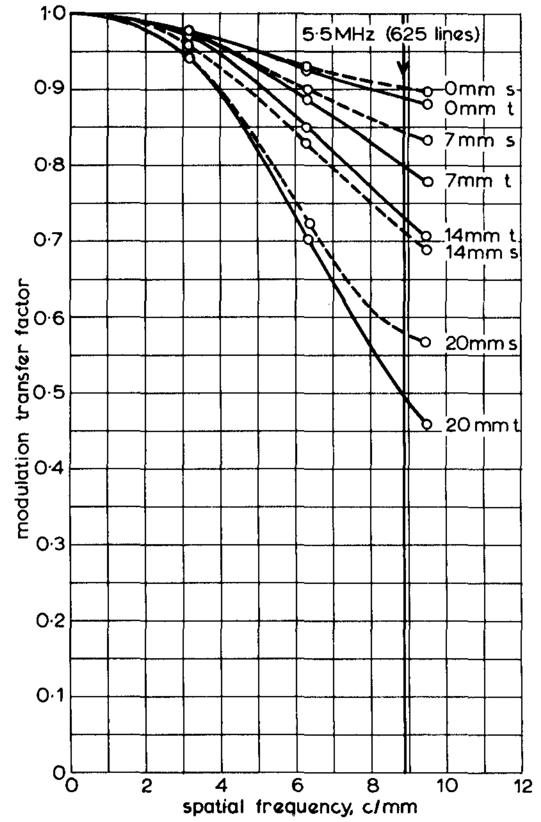

Fig. 23 - Modulation transfer function 10 × 35E5 zoom lens. 60 mm focal length at f/3·8, test object at infinity, optimum axial 9 c/mm focus

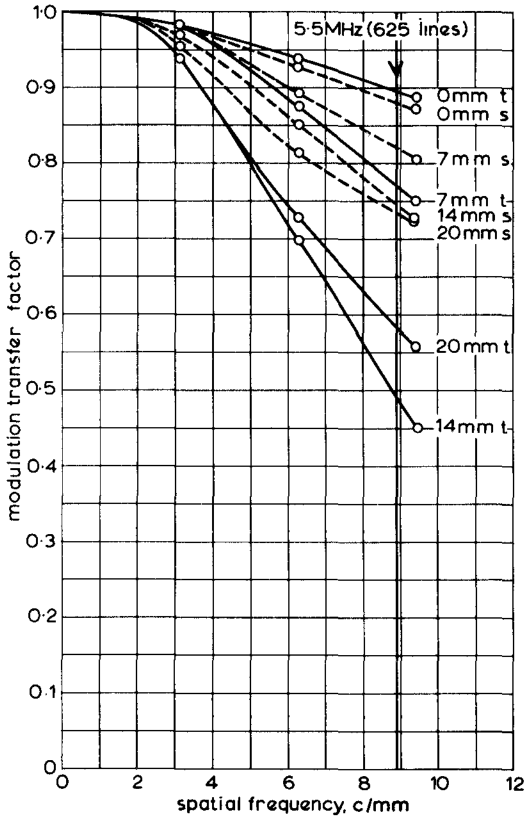

Fig. 24 - Modulation transfer function 10 × 35E5 zoom lens. 150 mm focal length at f/3·8, test object at infinity, optimum axial 9 c/mm focus

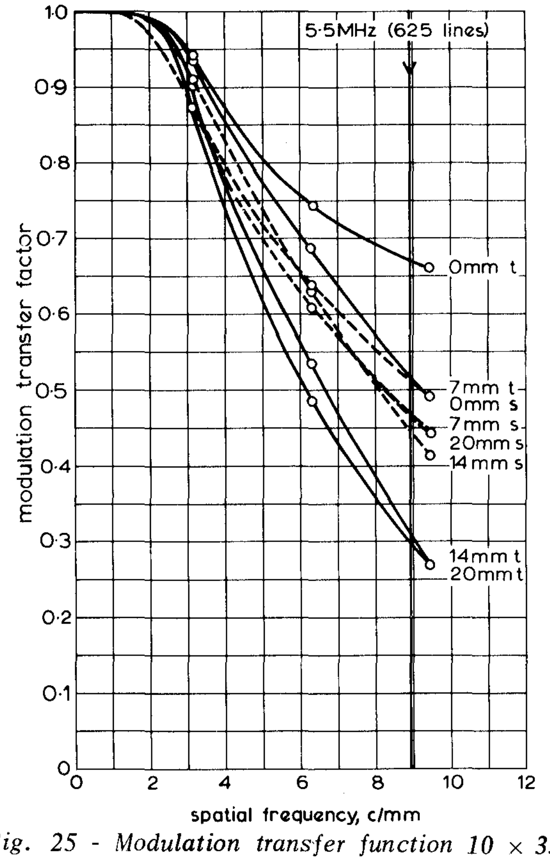

Fig. 25 - Modulation transfer function 10 × 35E5 zoom lens. 350 mm focal length at f/3·8, test object at infinity, optimum axial 9 c/mm focus

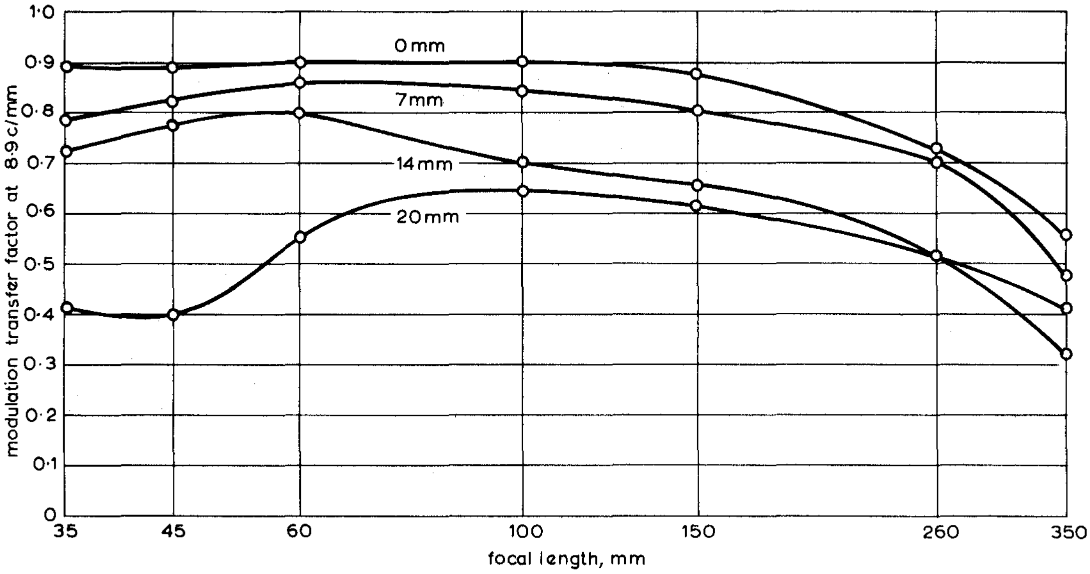

Fig. 26 - Modulation transfer factor at 8·9 c/mm. 10 × 35E3 lens at f/3·8, test object at infinity, optimum axial focus, average of sagittal and tangential m.t.f.

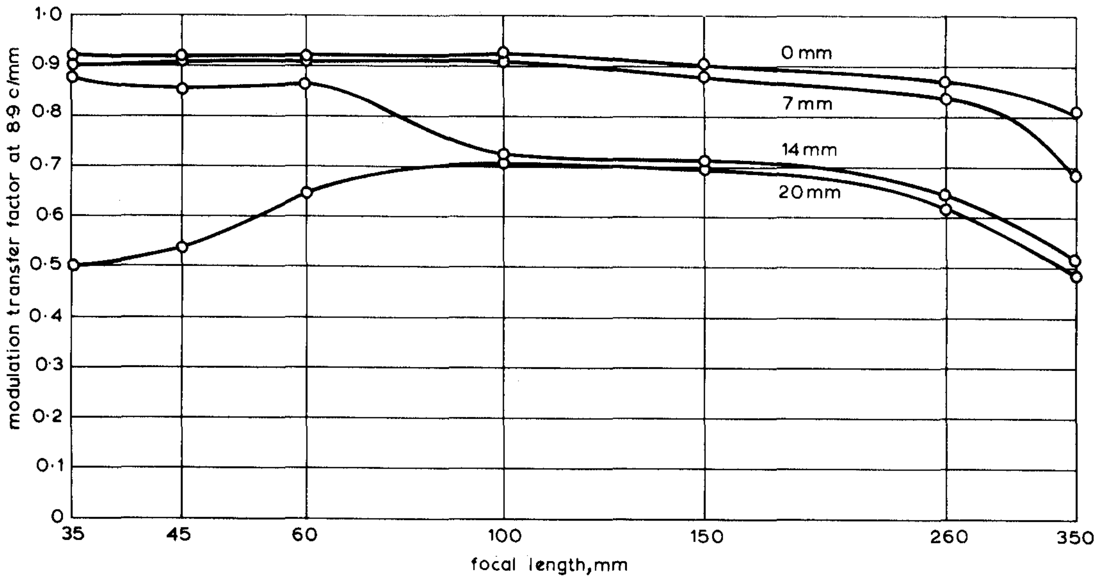

Fig. 27 - Modulation transfer factor at 8·9 c/mm. 10 × 35E3 lens at f/5·6, test object at infinity, optimum axial focus, average of sagittal and tangential m.t.f.

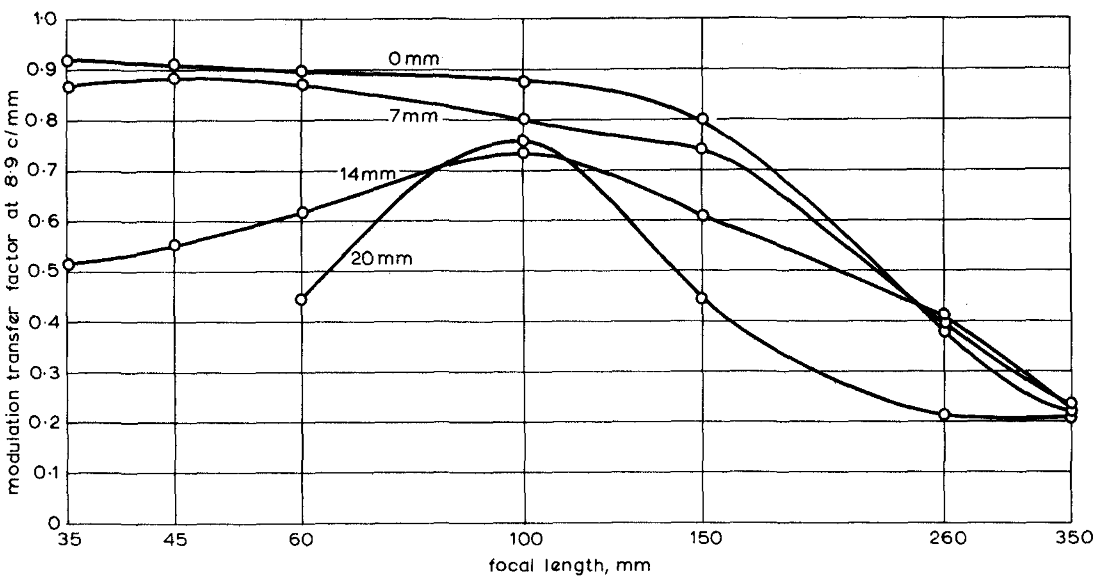

Fig. 28 - Modulation transfer factor at 8·9 c/mm. 10 × 35E3 lens at f/3·8, test object at 400 mm, optimum axial focus, average of sagittal and tangential m.t.f.

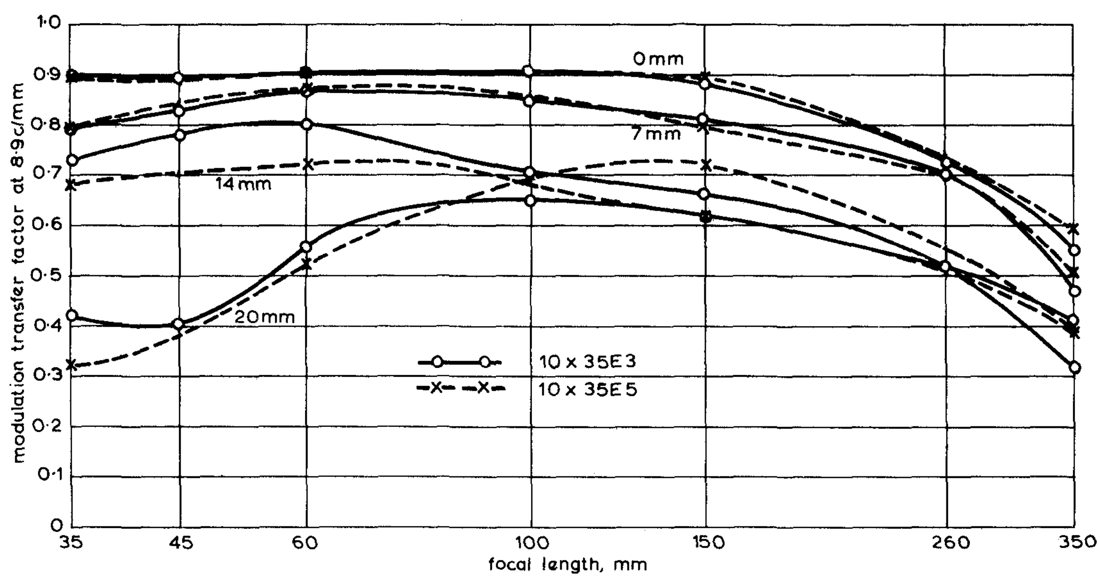

Fig. 29 - Modulation transfer factor at 8·9 c/mm, comparison of lenses types 10 × 35E3 and 10 × 35E5. Test object at infinity, optimum axial focus, average of sagittal and tangential m.t.f.

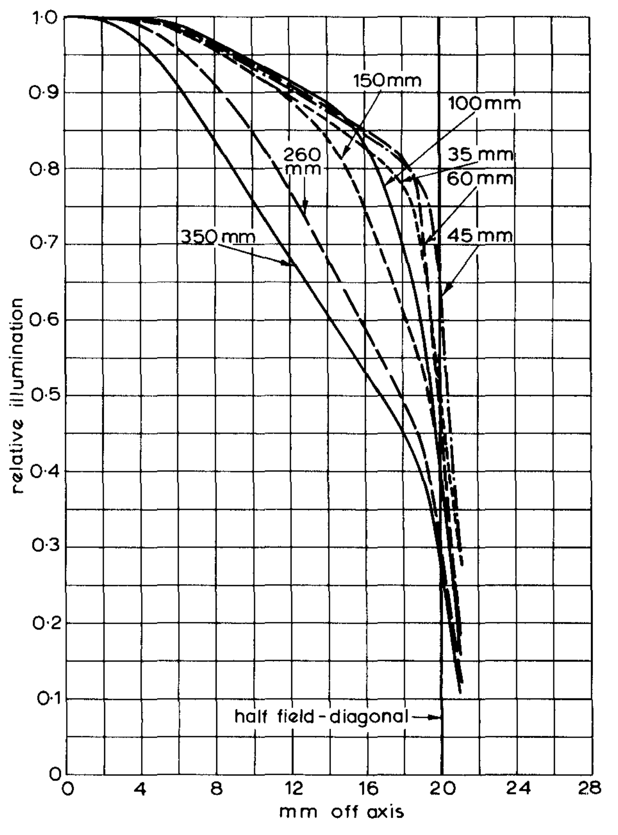

Fig. 30 - Vignetting characteristics 10 × 35E3 lens at f/3·8

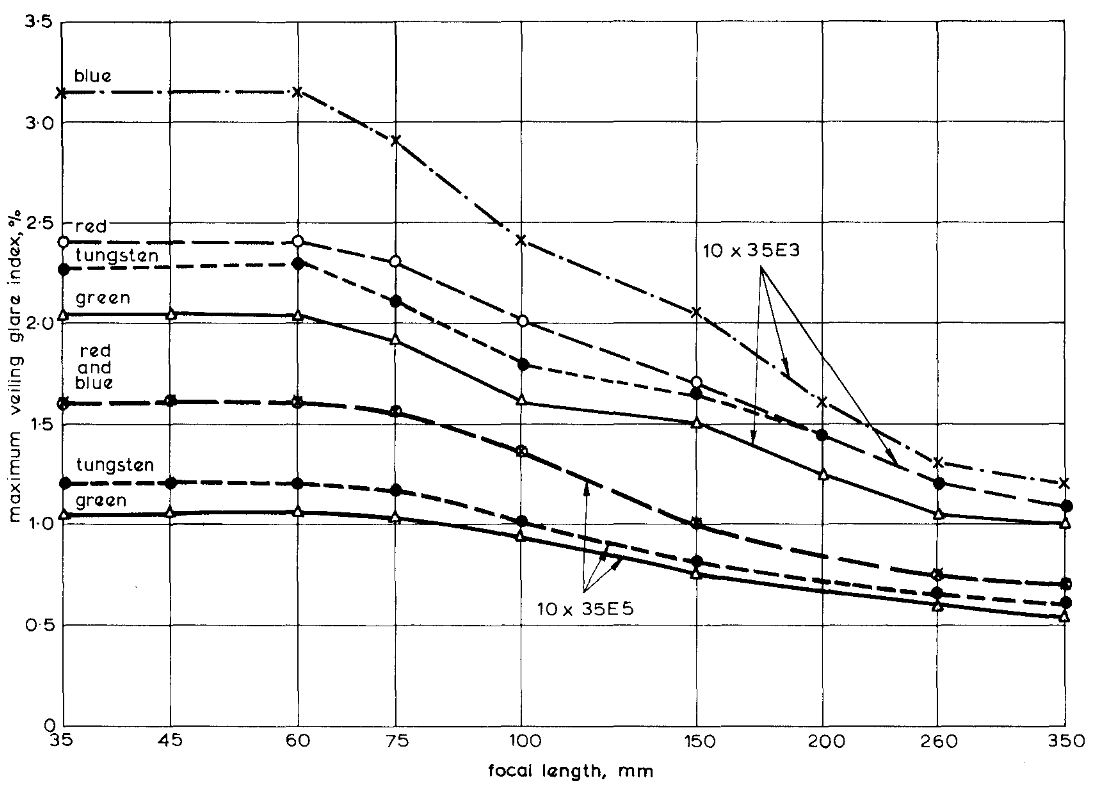

Fig. 31 - Maximum veiling glare index 10 × 35E3 and 10 × 35E5 lens, aperture setting f/3·8

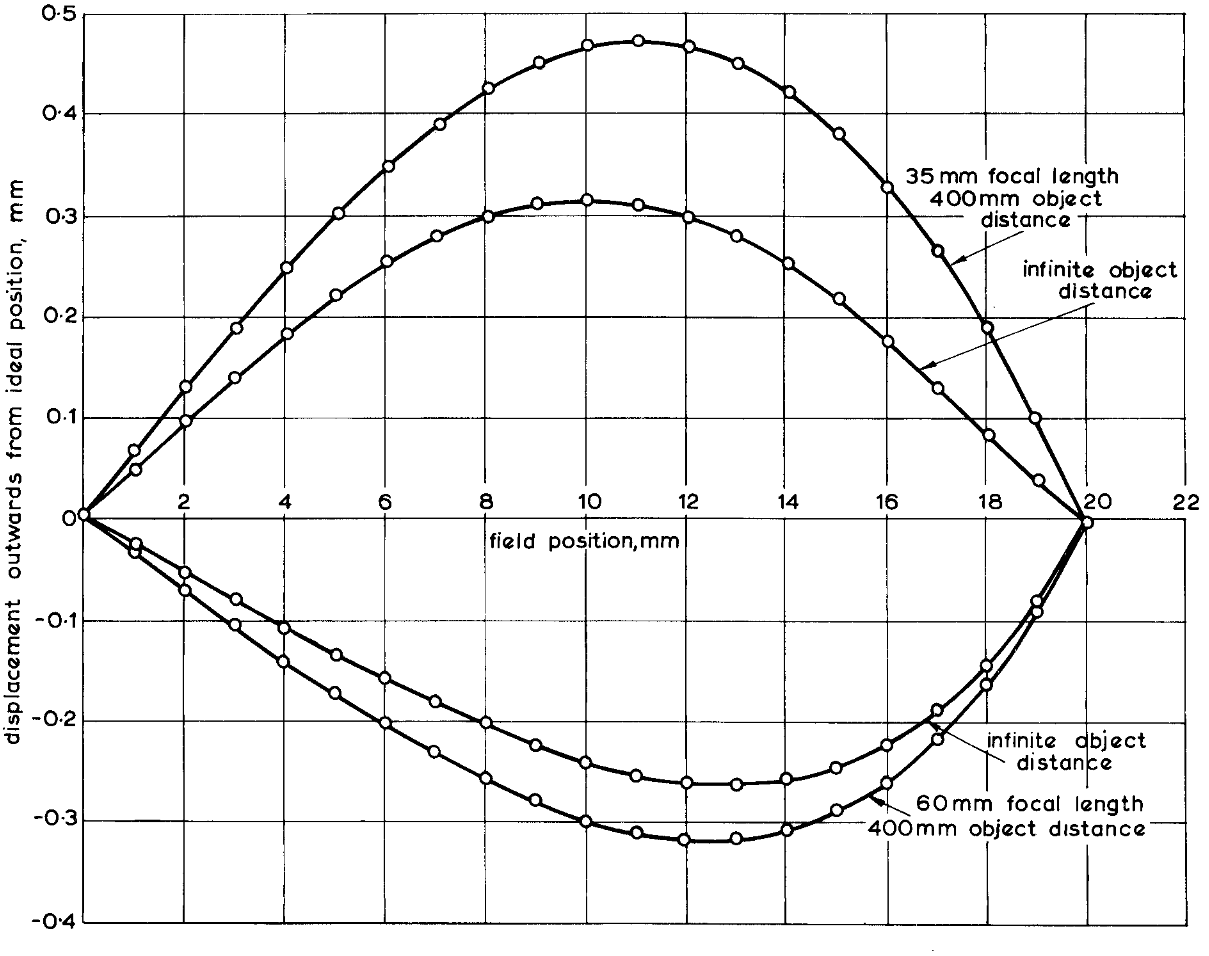

Fig. 32 - Geometrical distortion 10 × 35E3 zoom lens

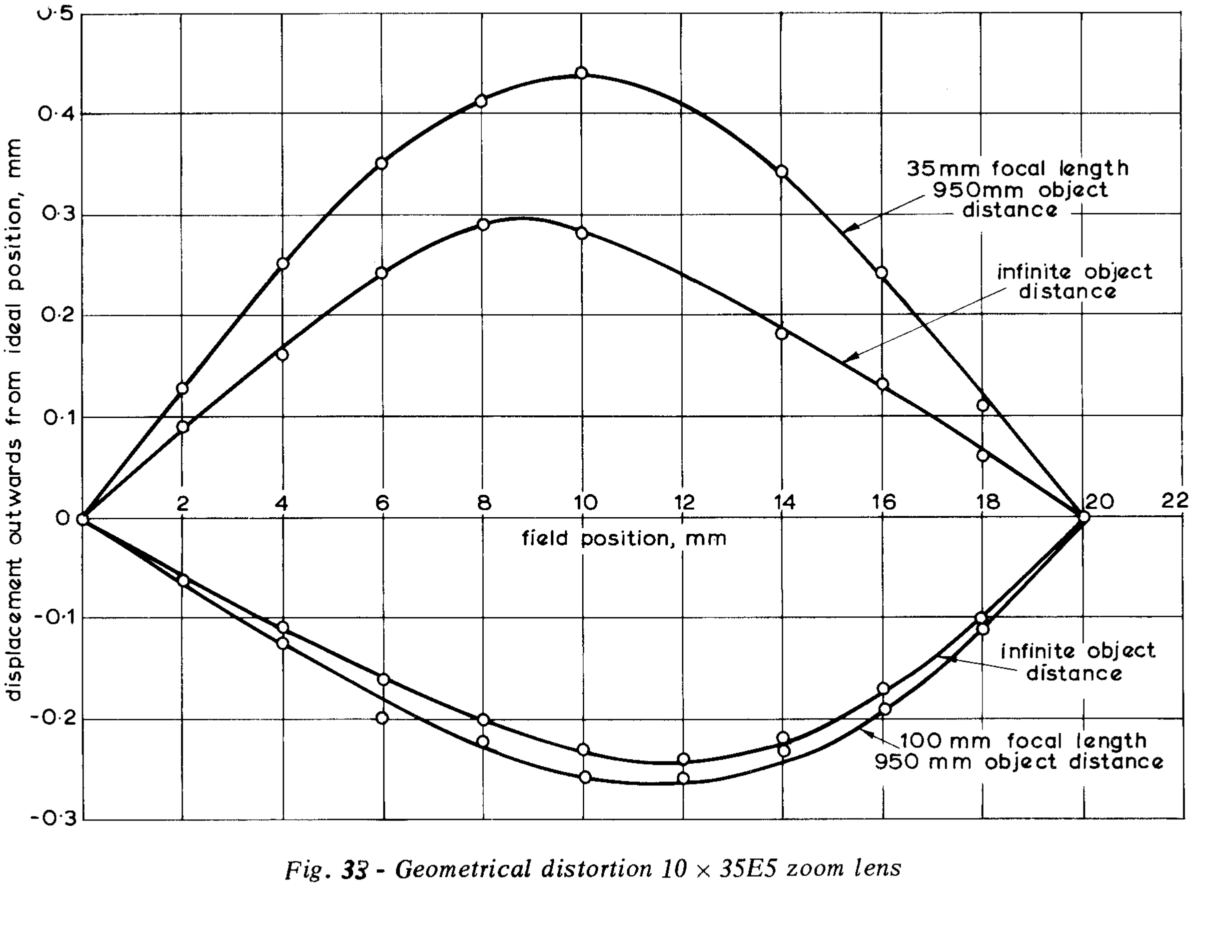

Fig. 33 - Geometrical distortion 10 × 35E5 zoom lens

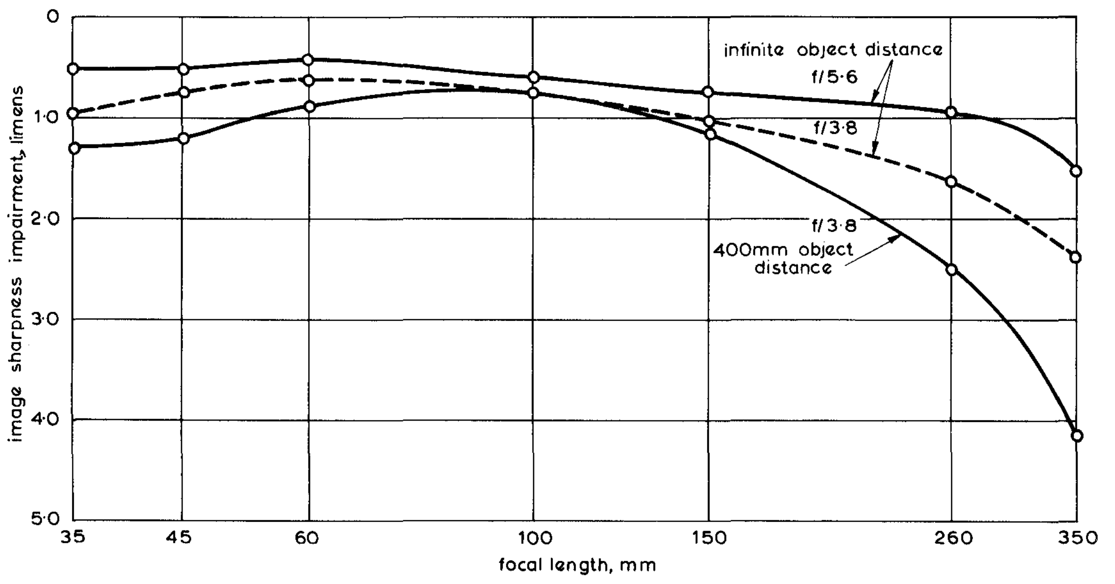

Fig. 34 - Subjective assessment of image sharpness 10 × 35E3 zoom lens

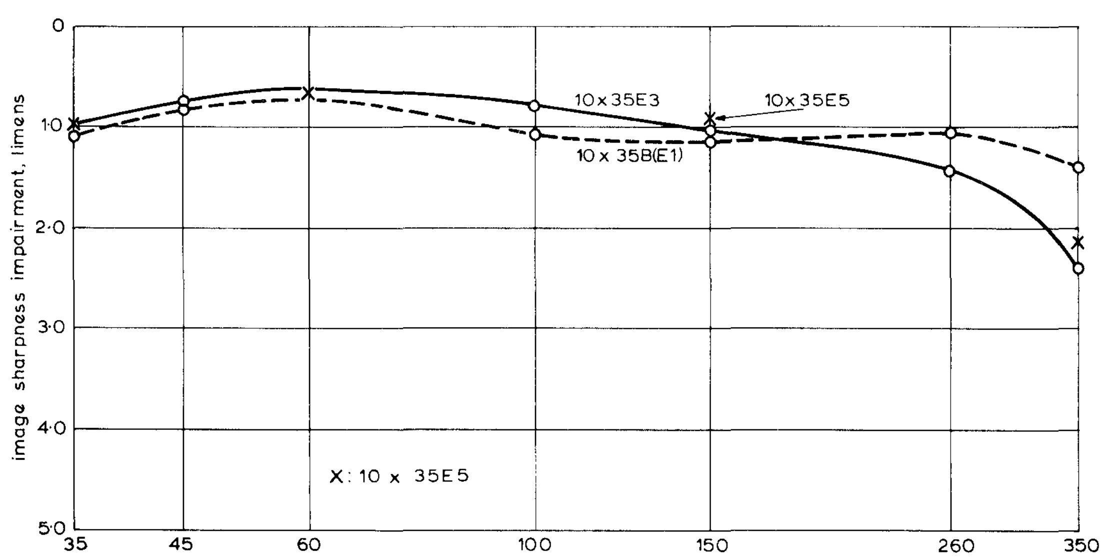

Fig. 35 - Subjective assessment of image sharpness Lenses types 10 × 35B(E1), 10 × 35E3, 10 × 35E5 aperture f/3·8, test object at infinity

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